EFFECTIVE NUMERICAL METHODS FOR VEHICLE DYNAMICS

FINAL PROGRESS REPORT

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13. ABSTRACT (Maximum 200 words)

This research project focussed on the enhancement of current vehicle simulation capabilities of TARDEC. Problems addressed included development of efficient numerical methods for solving equations of motion with high-frequency oscillations, and development of methods and software for sensitivity analysis and optimal control of engineering systems including multibody mechanical systems.

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1 Statement of the problem studied

This research project focussed on the enhancement of current vehicle simulation capabilities of TARDEC. Problems addressed included development of efficient numerical methods for solving equations of motion with high-frequency oscillations, and development of methods and software for sensitivity analysis and optimal control of engineering systems including multibody mechanical systems.

2 Summary of the most important results

High-frequency oscillations in nonlinear ODE/DAE systems are a problem in vehicle simulation because following the oscillations necessitates the use of an extremely small timestep. However, many of the oscillations are not important for the overall numerical solution. We have shown that methods based on local linearization can fail because the local eigenstructure of the problems oscillates at the high frequency. Experiments have demonstrated that certain implicit methods combined with automatic stepsize control can damp out the oscillation safely, in regions where its amplitude is too small to be important. The usual stepsize selection strategies must be modified so that they are correct for the limiting high-index DAE. There is also some theory to support this technique for the equations of motion. However, once the stepsize is increased, problems with Newton iteration convergence again restrict the timestep. These problems are also due to the rapidly changing local eigenstructure. Some formulations of the equations of motion are more advantageous than others in terms of Newton iteration convergence for highly oscillatory systems. A coordinate-split (CS) method has been developed that, together with a modified Newton (CM) iteration is particularly effective. Numerical results for a number of highly oscillatory multibody systems demonstrate that the new method is particularly effective for highly oscillatory systems where the oscillation is small and can be damped. Theory was developed which explains the Newton convergence results.

A new family of second-order methods called DAE α-methods for solving the

equations of motion for flexible mechanism dynamics has been developed. These methods, which extend the alpha methods for ODEs of structural dynamics to highly nonlinear DAEs, possess numerical dissipation that can be controlled by the user. Convergence and stability analysis verify that the new methods introduce no additional oscillations and preserve the stability of the original system. Convergence of the Newton iteration is achieved via the coordinate-split modification to the iteration. The new methods have been shown to be highly robust and efficient for a variety of problems including a bushing model and flexible slider-crank.

A new software package, DASOPT, was developed for optimal control and design optimization of large-scale differential-algebraic systems. These are optimization problems with nonlinear equality and inequality constraints which include satisfying the DAE system. There are many applications, including multibody systems. In DASOPT, the time interval is divided into subintervals and the problem is solved via a multiple-shooting type method. This allows the use of efficient DAE software. The derivatives required by the optimization are computed via efficient DAE sensitivitvity software that we developed.

3 Publications and Technical Reports

L. R. Petzold and J. Yen, *An Efficient Newton-Type Iteration for the Numerical Solution of Highly Oscillatory Constrained Multibody Dynamic Systems*, SIAM J. Sci. Comput. 19, No. 5 (1998), pp. 1513-1534.

L. Petzold, J. Yen and S. Raha, *A Time Integration Algorithm for Flexible Mechanism Dynamics: The DAE α-Method*, Computer Methods in Applied Mechanics and Engineering 158 (1998), pp. 341-355.

P. N. Brown, A. C. Hindmarsh and L. Petzold, *Consistent Initial Condition Calculation for Differential-Algebraic Systems*, SIAM J. Sci. Comput. 19, No. 5 (1998), pp. 1495-1512.

W. Zhu and L. Petzold, *Asymptotic Stability of Hessenberg Delay Differential-*

Algebraic Equatsions of Retarded or Neutral Type, Applied Numerical Mathematics 27 (1998), pp. 309-325.

L. Petzold, L. Jay and J. Yen, *Numerical Solution of Highly Oscillatory Ordinary Differential Equations*, Acta Numerica 1997, pp. 437-484.

4 List of all participating scientific personnel

The personnel participating in this project were: PI: Linda R. Petzold, Post-doctoral research associates: Jeng Yen, Laurent Jay; Graduate research assistants: S. Raha, S. Li, D. Clancey, W. Zhu

5 MS or PhD Degrees Conferred

Douglass Clancey, MS Computer Science, U. of Minn., 1998; Soumeyendou Raha, MS Scientific Computation, U. of Minn., 1997; Shengtai Li, PhD Computer Science, U. of Minn., 1998; Wenjie Zhu, PhD Computer Science, U. of Minn., 1998.

6 Report of inventions

None.